Bottom-up approaches towards complex nanomaterials: combining tools for the construction of multiscale nanosystems

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Current "bottom-up" techniques for nanomaterials synthesis permit to produce an impressive palette of nanometric objects: nanoparticles, nanorods, nanotubes, block copolymers, dendrimers, nanostructured films, etc… These "Nano-Building Blocks" (NBB) can be currently produced in a reproducible way with a great variety of tuned features, including composition, dimensions, anisotropy and surface modification. Properties derived from structure, size or surface can be therefore accurately controlled or even designed.

In the last years, there is an increasing interest in combining these NBB into more complex functional structures that present properties at different length scales: nanoscopic, mesoscopic and micrometric. The possibility of accurately controlling the NBB properties, and combining soft chemistry approaches permits to create complex integrated materials, where different NBB are co-assembled in space. The properties of these systems are derived from the properties of the NBB that form them, but also in their synergy. This "build-and-assemble" paradigm is "biomimetic", similar to the processes that take place in naturally occurring materials such as nacre, shell, bone and teeth.

In this work, several strategies will be presented that lead to complex nanomaterials formed by the combination of inorganic and organic NBBs. In particular, mesoporous materials derived from the combination of sol-gel chemistry and self-assembly of surfactants will be described. Mesoporous materials with amorphous or nanocrystalline inorganic frameworks present high surface area (100-1000 m^2 g^{-1}), and ordered arrays of monodisperse pores with tailored size in the mesoscale (2-50nm). Mesoporous Thin Films (MPTF) with oxide, phosphate, carbon-or hybrid organic-inorganic frameworks present interesting sensing, catalytic, electrical and optical properties, tuned by the pore size and geometry, wall composition, crystalline or amorphous character and surface features. Well-defined monodisperse sized pores act as nanocavities with controlled environment and behaviour.

We have explored the production of accessible MPTF with their pore surface or interior modified by organic functional groups or nanoparticles. The presence of organic functional group leads to new sorption or controlled transport properties, opening the way to nanofiltering membranes. Ordered mesopores were used as an array of nanoreactors, permitting the inclusion of nanoparticles (NP), leading to tunable optical properties. Multilayer MPTF systems present a great variety of new properties: localized chemical reaction control, modulable photonic crystal behaviour, or enhanced Raman effects. Selected examples of optical and chemical behaviour of these multiscale materials will be presented.

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